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Thermodynamic Simulation in Eco-Friendly Aquadest Production Through Compression System Method Combined with Steam Power Plant as Heat Source

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ABSTRACT

Access to clean water and sanitation is one of the Sustainable Development Goals (SDGs), a global action plan agreed upon by world leaders. Water demand is increasing every year. As much as 97% of the water on earth is seawater, which requires desalination technology to convert seawater into freshwater that will be used to meet daily human needs. It is necessary to continue to develop environmentally friendly clean water treatment technology to overcome the problem of freshwater crisis. Research related to clean water treatment technology needs improvement in order to have a high effectiveness value to be applied and developed in areas with clean water crisis. Therefore, this study aims to produce distilled water by utilizing heat from the condenser of a steam power plant. The cooling water from the condenser must first be throttled to allow the vapor and liquid extraction to occur. Next, the steam is compressed to raise the temperature. After the compression process, the steam must be condensed using a water-cooled condenser to produce the distilled water in order to get maximum distilled water yields and low energy consumption. In this study, the lowest SEC (Specific Energy Consumption) was -1194.02kJ/kg of distilled water with the mass flow rate of 0.996 kg/s. To overcome the environmental problems, the condenser temperature was lowered to 41.5°C, and the PPTD (Pinch Point Temperature Difference) by 10 made the temperature discharge to seawater drop to 31.5°C. The lowest energy consumption can be obtained by setting the temperature in the cyclone separator to 22°C and the mass of water discharged to the sea by 99%, which lowers compressor energy consumption.

1. Introduction

Water is essential for people's health and well-being. The problem of water shortages generally occurs in developing countries. This will hinder the improvement of the quality of life. Most of the world's water is salt water, and only a tiny part of the total water on the planet is accessible as fresh water. To meet the need for clean water for developing communities worldwide, it is becoming increasingly clear that desalination has a more significant role to play. Desalination plants in

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developed countries are often large-scale, require substantial capital and infrastructure, and rely on state-of-the-art technology with a team of experts available to operate and maintain the plant. Most developing countries, consisting of small cities, coasts, and others, face limited clean water. Global water usage is reported to increase by six over the past 100 years [1]. For instance, the use of water as a cooling medium is critical, which signifies a difference in heat transfer performance (especially in power plants) [2,3] and even water is used to generate electricity, where most conventional power plants require various working fluids (such as water, gas, steam and wind) for the turbine working fluid as a conversion system from mechanical energy to electricity [4]. In addition, nearly 50% of households in urban / village areas, especially in Indonesia's coastal areas, difficult to obtain clean water. As the world's population expands, so does the demand for clean and safe water [5]. As we all know, the sea covers over 70% of the earth's surface. Every person needs roughly 60 liters of clean water every day [6]. Desalination technology is becoming more and more critical in supplying water to cities and industries. The desalination system uses only a tiny portion of the nation's total energy consumption. For instance, less than 1.4% of Israel's total energy consumption is needed to produce 600 million m^3 of desalinated water annually. Major issues include the release of greenhouse gases and air pollution, harm to marine habitats on the intake side, and the discharge of chemical-rich concentrate at relatively high temperatures and salinities. The data that are available show that after complete dilution with saltwater, being affected by salinity and rising temperature at the site of concentrate discharge further lowers the effect [7].

It takes a long time to produce clean water. Separating the hazardous particles included in raw water is required to achieve clean water. Plain water has mineral content, high salt level, microorganisms, and contaminants such as these tiny particles, making it unfit for human consumption. The desalination process is a common method for converting seawater into clean water. Desalination is basically a separation procedure that reduces the number of dissolved salts in salt water to make it drinkable. Desalination processes can be divided into three basic categories: membrane, thermal, and developing desalination techniques [8]. The methods of reverse osmosis (RO), electrodialysis, and refining all require energy from non-renewable fossil fuels [9]. In other words, the RO technique is considered as the most promising technique, but its power consumption is much higher than all other techniques. Yahya *et al.,* states that for countries with hot climates, wastewater reclamation using reverse osmosis technology can be a significant low-cost source of freshwater [10]. Therefore, a desalination system is needed to meet the increasing demand for fresh water, especially one that is eco-friendly and economical. Combining desalination systems with solar energy technology is one method that allows for reducing the need for fossil fuel energy sources [11]. On the other hand, the use of solar panel technology is still inefficient because solar panels' efficiency ranges between 12% to 14% [12,13]. Installing solar hybrid PV and wind power generation with electrochemical storage is a solution that reduces the Levelized Cost of Electricity (LCOE) while still taking into account the additional cost of the desalination plant and the need for financial assistance to shorten the construction period [14].

Aside from the methods described above, there are other methods for purifying water. The use of Dielectric Barrier Discharge Reactors is one of these ways. This approach uses the necessary temperatures to make it safe to use [15]. Surajbhan Sevda and colleagues They purified water using microbial respiration and increased the volume of a single seawater desalination chamber from 3 ml to 15 L [11]. Sevda *et al.,* purified water using microbial respiration, increasing the volume of a single seawater desalination chamber from 3 ml to 15 L [11]. Ahmed Hegazy gathers water via a vacuum evaporator to capture steam condensation, with an energy consumption of 1-8 kWh/kg [16]. Ebrahimi Khosrow investigated the desalination of saltwater using low-temperature heat sources. To follow up on the above researchers' efforts to produce desalination water [17]. Researchers have competed on numerous occasions to develop SWRO (seawater reverse osmosis) technology to create desalination water [18]. Several thermal desalination simulations are carried out by utilizing the phase difference due to the pressure drop on the cyclone separator. The water vapor produced in the cyclone separator is carried out in stages to produce distilled water [19,20].

The waste heat of flue gases can be used to improve the performance of combined cycle power plants, according to numerous studies [21,22]. Although the process benefits of the power cycle have been established, no careful use of flue gas heat to enhance the performance of thermal desalination has been thoroughly researched. As a result, the refiner's performance ratio rises when hot steam condensate is used, and less fuel is required for subsequent combustion as a result [23].

The goal of this paper is to combine the system of power plant with the desalination plant system. However, combining the desalination plant with the steam power plant system requires more energy. This study is a continuation of previous research which only carried out variations in terms of The mass of water discharge (m_{WD}) and pressure in cyclone separators are the independent variables. So in this study, variations of the temperature in the condenser and pinch point difference in condenser were also carried out because it has potential in aquadest productivity [24]. Not much research has been done on aquadest productivity by combining it with a power plant, so it needs further review. This study develops an innovation that makes use of the steam power plant's warm cooling water condenser output. Warm water is typically discarded back to sea in steam power plants, therefore, warm water will be throttled in this system to reduce pressure and temperature. Warm water is normally thrown into the sea without being utilised after the process. High-temperature water is hazardous to the environment because it can harm the ecology.

In this scenario, some hot water waste is throttled and returned to the desalination system, which allows the warm water phase to be converted to water vapour and aquadest. Aquadest production differs from water purification production in that it relies on changes in the water phase, requiring pure products from condensed water vapor. Another benefit of this instrument is that it can make aquadest at a low cost. Adding this instrument to a steam power plant does not increase the system load; nevertheless, adjusting the condenser pressure increases the power generated by the plant [25]. This technology can also lower the temperature of wastewater that is discharged into the sea, making it more environmentally friendly.

The energy consumption at the steam power plant can be lowered in the MSF (multi-stage flash) desalination process by utilizing the heat emitted by turbine condensation to provide the primary thermal energy needed for the desalination process. Low steam condensation temperatures around ambient temperature are required for high-efficiency electric energy production. It is possible to improve the turbine power provided by the steam power plant by lowering the pressure of the steam power condenser plant [26]. The pinch point temperature difference (PPTD) can also be adjusted to improve condenser performance [27]. Variations in the volume of water discharged directly into the sea and adjustments in water pressure in cold water container tubes can be done in addition to the two variations mentioned above to improve aquadest production and thermodynamic efficiency [28]. A desalination system with an eco-friendly compression system that is integrated with a steam power plant has a big impact. in addition, studies related to the effect of centrifugal compressor performance are greatly influenced by impeller modifications, which can improve centrifugal compressor performance and also increase the outlet mass flow rate & pressure ratio. In addition, several researchers have shown that in order to extend the stable operating range of centrifugal turbocharged compressors requires proper maintenance, but their performance is still inadequate in most conditions [29]. In this paper, we will use the throttling process approach to describe the influence of temperature in the cyclone separator, pinch point difference at the condenser, and percentage of mass water outflow on aquades production and specific energy consumption with an eco-Friendly compression system. However, this research aims to locate the least amount of SEC while producing the most aquadest possible.

2. Methodology

In this research, we use the thermodynamic simulation method. The thermodynamic simulation method applies theoretical calculations to power plants to determine specific energy consumption. In this scenario, we take data from a 50 MW steam power plant with an inlet temperature of 510°C, an inlet pressure of 8.9Mpa, a condenser temperature of 47.5°C, a condenser pressure of 10.89 kPa, aquadest condenser temperature out 44°C, and a steam turbine efficiency of 87 percent isentropic. However, in this simulation, the temperature in the condenser, pinch point difference in condenser, mass water discharge, and cyclone separator temperature vary. In this simulation, the mass flow in the powerplant cycle is assumed to be 1kg/s.

Figure 1 shows a flow diagram of a desalination plant integrated into a steam power plant. In this study, the system will be simulated based on thermodynamic theory. Seawater entering the desalination system will mix with brine water pumped from the cyclone separator, as shown in this flow chart. Due to a little increase in temperature, the enthalpy of the brine water combination increases during this mixing process. The following equation can be used to calculate the enthalpy value of this mixture.

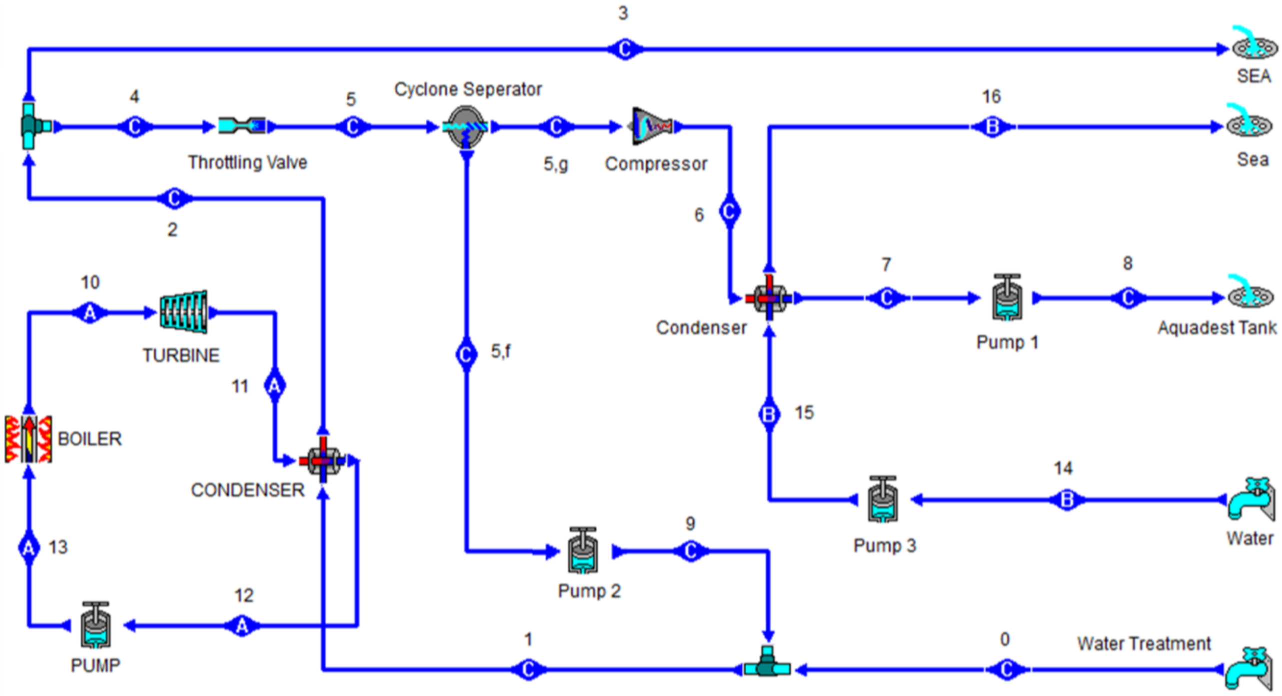

Fig. 1. Schematic diagram of throttling process

$$h_1 = (1-Y)(1-X)h_9 + (X(1-Y)+Y)h_0 \quad (1)$$

The enthalpy is h, the essential vapor fraction is X, and the mass water discharge fraction is Y. The equation below can be used to calculate the brine water enthalpy h_9.

$$h_9 = h_{5,f} + v(p_1 + p_5) \quad (2)$$

p_1 is the pressure of mixing water, and p_5 is the pressure in the cyclone separator, where $h_{5,f}$ is the enthalpy of saturated liquid from the cyclone separator and $h_{5,f}$ is the enthalpy of saturated liquid from cyclone separator. The enthalpy of the brine water discharge from pump 2 is h_9. The mass fraction of vapor X can be computed using the following equation.

$$h_5 = h_{5,f} + X\left(h_{5,g} - h_{5,f}\right) \tag{3}$$

where $h_{5,f}$ is the saturated liquid enthalpy from the cyclone separator and $h_{5,g}$ is the saturated vapour enthalpy from the cyclone separator. The enthalpy in a cyclone separator is h 5. The blended water then goes to the condenser. The latent heat from the working fluid in the steam power plant will be absorbed by water entering the condenser. The following equation, Q condenser, can be used to compute the amount of heat released in the steam power plant's condenser (Q_c).

$$Q_c = m_T(h_{11} - h_{12}) \tag{4}$$

$$Q_c = m_{cw}(h_2 - h_1) \tag{5}$$

By substituting Eq. (4) and Eq. (5), the mass flow of cooling water (m_{cw}) can be calculated. Assume the turbine working fluid mass flow (m_T) is 1 kg/s, then use the equation below to compute the mass of aquadest production (m_{Aq}).

$$m_{Aq} = m_{cw}\left(X(1 - Y)\right) \tag{6}$$

Using the function of enthalpy is the function of pressure 2 (p_2) and temperature 2 (T_2), the value of the enthalpy outlet condenses cooling water (h_2) may be found. The equation below can be used to compute temperature 2.

$$T_2 = T_{11} - \Delta T_{pinch} \tag{7}$$

Before determining the total energy consumption of the desalination plant, calculate the increase in turbine power. The decrease in temperature at the condenser power plant from 42.5°C to 37°C causes the turbine output to increase.

$$\Delta P_{turbine} = (h_{10} - h_{11new}) \dot{-} (h_{10} - h_{11old}) \tag{8}$$

Then the equation below can be used to compute the power of pump 1 ($P_{pump\ 1}$), pump 2 ($P_{pump\ 2}$), pump 3 ($P_{pump\ 3}$), and the vapour compressor (P_{comp}).

$$P_{pump\ 1} = \dot{m}_{Aq}\,(101.325 - p_7) \tag{9}$$

$$P_{pump\ 2} = \dot{m}_{cw}\,(1 - X)(1 - Y)(h_9 - h_{5,f}) \tag{10}$$

Before computing the power of pump 3, the equation below must be used to compute the Q condenser aquadest (Q_{cAq}).

$$Q_{cAq} = \dot{m}_{cwAq}\,C_{p,w}\Delta T \tag{11}$$

where ΔT is the temperature difference at the condenser aquadest, and $C_{p,w}$is the specific heat of cooling water aquadest. The equation below can be used to calculate the power of pump 3.

$$P_{pump\ 3} = \dot{m}_{cwAq}\, v_7 \Delta p \tag{12}$$

Pump 3 is used to pump cooling water to the aquadest condenser; the pressure differential (Δp) can be as high as 100 kPa to overcome friction in the pipe and condenser. The following equation can be used to calculate the vapour compressor's power.

$$P_{comp} = X(1-Y)\dot{m}_{cw}\left(h_6 - h_{5,g}\right) \tag{13}$$

The equation can be used to calculate specific energy consumption (SEC) from all of the power requirements employed in this way of throttling.:

$$SEC = \frac{P_{comp} + P_{pump\ 1} + P_{pump\ 2} + P_{pump\ 3} - \Delta P_{turbine}}{\dot{m}_{Aq}} \tag{14}$$

3. Results

In this simulation, the pinch point temperature difference (PPTD) is varied from 0 to 10, and the condenser power plant temperature is varied from 38°C to 48°C. We have also varied the temperature in the cyclone separator from 2°C to 22°C and the mass of water discharge from 89% to 99%. The purpose of the varied above is to find the best aquadest production with the lowest SEC. The PPTD is 10, and the condenser temperature varies from 38°C to 48°C.

Based on research by Kosasih has been done before, we can conclude that the minimum of SEC is on the cyclone separator temperature 22°C. In this Figure 2, shows the minimum SEC value at the temperature of the cyclone separator 22°C with a value of -1194 kJ / kg aquadest at the condenser power plant temperature of 41.5°C. The trend of the graph is formed at each cyclone separator temperature. However, the lowest SEC value on each cyclone separator temperature variation will shift in the temperature value at the condenser power plant. In this case, the increase in temperature at the condenser power plant, which causes energy consumption at pump 1, pump 2, pump 3, and vapor compressor smaller, it causing the addition of turbine power per aquades produced will be more significant. So, the total consumption of pumps and compressors has reduced the accumulation of turbine power per aquades produced that causes the SEC value to be lower. However, at one point after reaching the lowest SEC value, the SEC increased again. The increase of the value of SEC due to the addition of turbine power is slightly accompanied by lower aquadest production, so the SEC will continue to rise again.

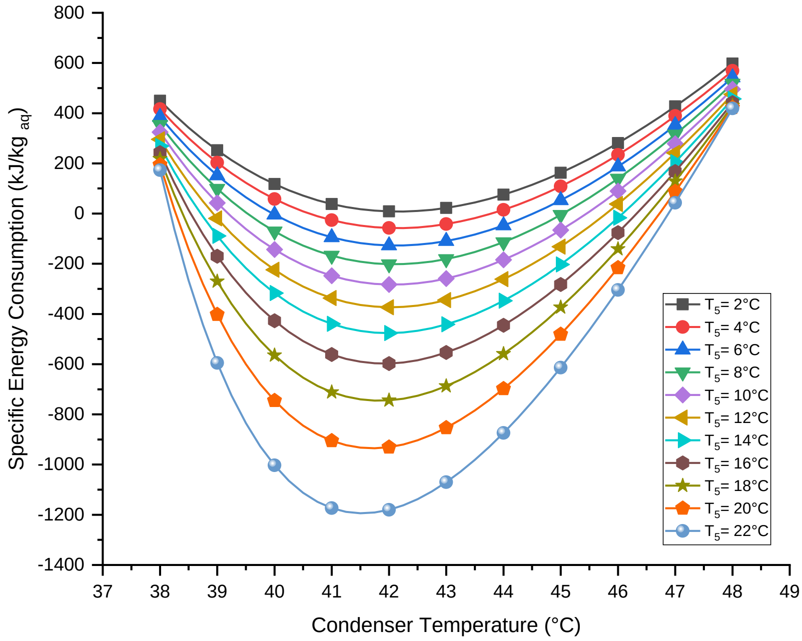

Fig. 2. Graph Specific Energy Consumption vs Condenser Temperature at different temperatures in a cyclone separator

At the condenser power plant temperature of 41.5°C and cyclone separator temperature of 22°C the lowest SEC value was obtained -1194 kJ / kg aquadest with a production of 0.996 kg / s aquadest as shown in Figure 3. In this condition, it is considered an optimum point if we vary in the temperature of the condenser power plant.

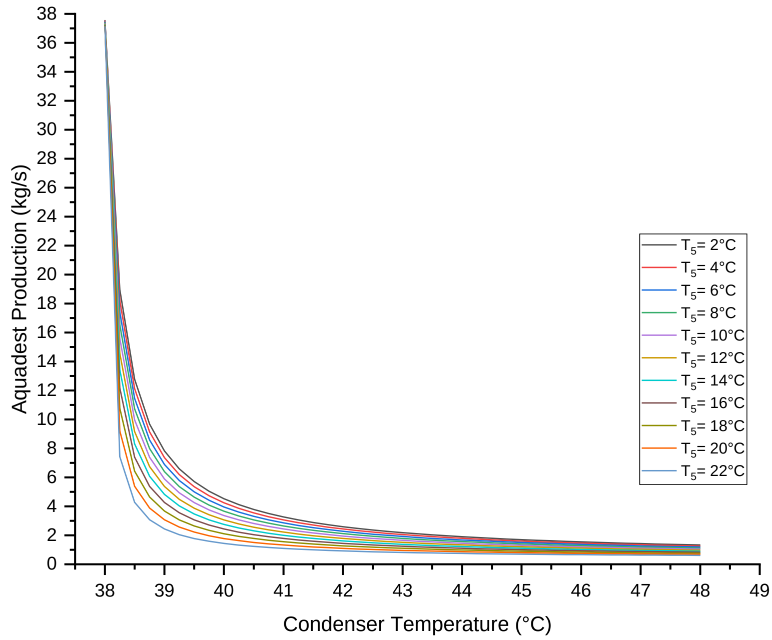

Fig. 3. Graph Aquadest Production vs. Condenser Temperature at different temperatures in a cyclone separator

Based on Figure 2 and Figure 3, we know the lowest SEC at condenser temperature 41.5°C, so we use it to vary the PPTD from 0 to 10. The Figure 4 shows that in addition to the higher temperature in the cyclone separator will cause the SEC obtained will be lower. Varying the Pinch Point Difference Condenser power plant will affect the SEC value. The more Pinch Point Difference Condenser power plant, the lower the SEC value. However, the PPTD condenser power plant value must also be adjusted. If the SEC value is lower, it will cause the aquadest produced to be smaller and the size of the condenser power plant to be larger than the standard size. The smaller PPTD Condenser power plant will cause water to be discharged into the sea to be higher than the specified standard for the environment. So, it will impact the damage to ecosystems in the sea. In this case, the best PPTD is 10 because the cooling water temperature outlet is 31.5°C

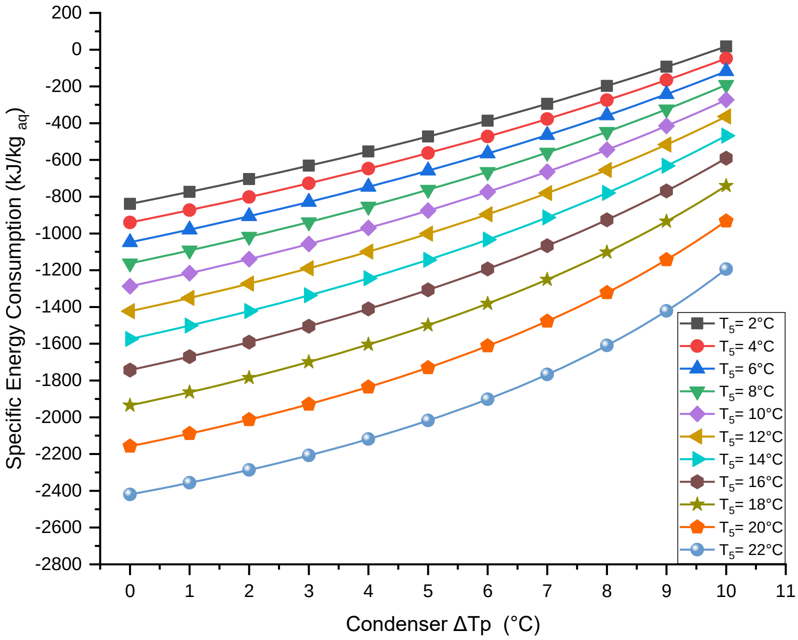

Fig. 4. Graph Specififc Energy Consumption vs. Pinch Point Difference Condenser power plant at different temperatures in a cyclone separator

The variation for the condenser temperature only from 39°C to 42°C as shown in Figure 5. In this case, we are limit the temperature of cooling water discharge to the sea until 32°C, and the maximum PPTD is 10. By varying the PPTD of the Condenser power plant, it affects the increase in aquadest production in each variation of the condenser temperature power plant.

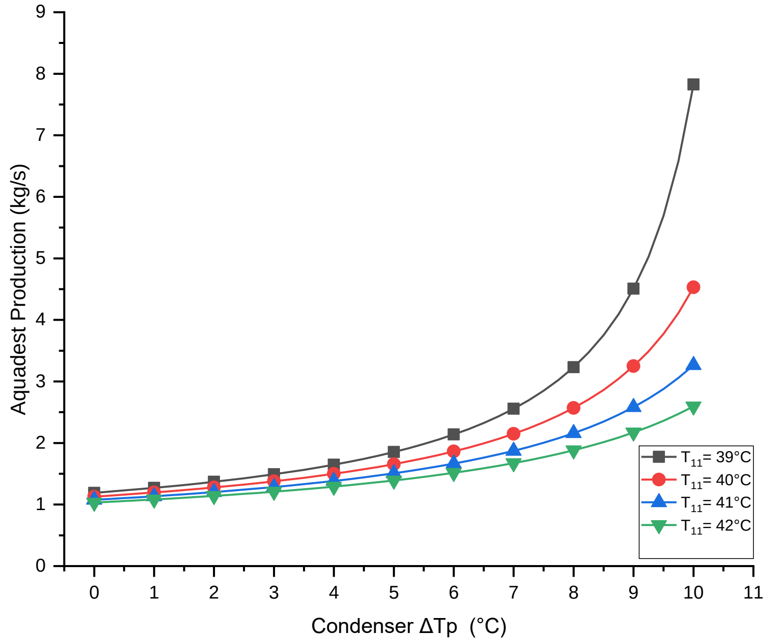

Fig. 5. Graph Aquadest Production vs. Pinch Point Difference Condenser power plant at different condenser temperatures

In the Figure 6, using temperature in cyclone separator at 22°C and the mass water discharge 99%. The condenser temperature at 38°C is not used. Because by using PPTD condenser power plant 10, causing the temperature inlet and outlet of the condenser is equal. This condition will make the cooling water temperature inlet the condenser equal to the temperature of the condenser outlet. It is impossible, so varying the temperature at the condenser 38°C is not the right choice. At PPTD 10 the lowest SEC is 42°C with SEC value -1180.34 kJ/kg aquadest.

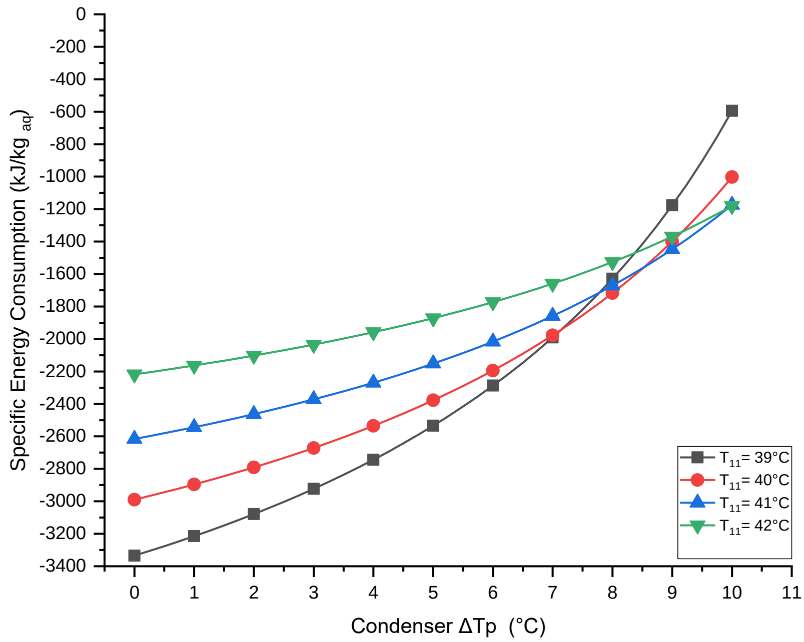

Fig. 6. Graph Specific Energy Consumption vs. Pinch Point Difference Condenser power plant at different condenser temperatures

According to Figure 6, the condenser pressure drops from 10.89 kPa at 47.5°C to 7.99 kPa at 41.5°C. The temperature drop is proportional to lowering the pressure in the condenser. Lowering the pressure or temperature in the condenser increases the steam power plant's output. Lowering the condenser temperature, on the other hand, will alter the cooling water temperature. The cooling water temperature of the condenser drops from 41.5°C to 31.5°C for the same PPTD condenser at 10°C. The condenser's cooling water will be discharged partially into the sea at 31.5°C, which is excellent for the environment because seawater's average temperature is between 28°C and 30°C.

The condenser temperature varies from 38°C to 48°C in the Figure 7, with mass water outflow being constant at 89% to 99%.

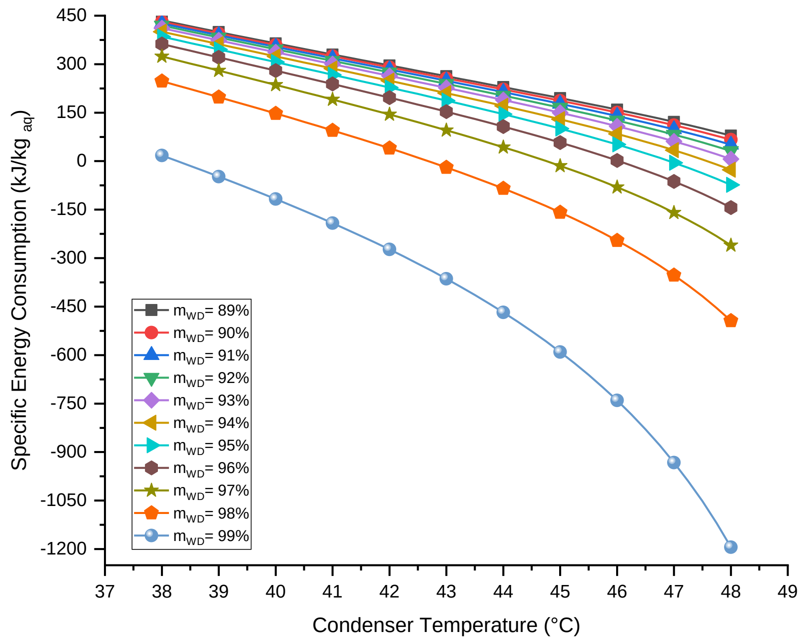

Fig. 7. Graph Specific Energy Consumption Vs. Condenser Temperature at the different percentages of mass water discharge

Figure 7 shows how the percentage of mass water outflow affects the system's SEC. The condenser temperature in this system is 41.5°C, and the PPTD is 10. The lowest SEC is -1194.02kJ/kg aquadest at 99 percent mass water discharge. The results show that the highest SEC is 435.33kJ/kg aquadest at 89 percent mass water discharge. According to the data above, the higher the mass water discharge to the sea, the lower the system's SEC. The effect of mass water discharge from 89% to 99% demonstrates the most significant reduction in SEC. The greater the mass water discharge to the sea, the lower the mass aquadest production. Pump 1, pump 2, pump 3, and the vapor compressor's power will be affected by the aquadest output. The energy consumption of the pump and vapor compressor will increase as the mass aquadest generation increases. However, as aquadest output grows, the specific energy of increased turbine power decreases. As a result of the graph above, the SEC now has a negative value.

In a cyclone separator, the pressure is a function of temperature saturation. For each mass water discharge, the graph's trend will show a drop in SEC as the pressure at the cyclone separator rises. If the pressure in the cyclone separator rises, the energy consumption and SEC for pump 2 and the vapor compressor will decrease.

According to the Figure 8, an increase in cyclone separator temperature decreased aquadest generation. At 99 percent mass water outflow and 22°C cyclone separator temperature, the minimum aquadest production is 0.99 kg/s, while the maximum aquadest production is 19.12 kg/s at 89 percent mass water discharge and 2°C cyclone separator temperature. At a constant percentage of mass discharge water, the lower temperature in the cyclone separator led the $h_{5,f}$ to decrease, while the h_5 remained constant. As a result, the difference between h_5 and $h_{5,f}$ grows. In the cyclone separators $h_{5,g}$ and $h_{5,f}$, the value of enthalpy as a function of temperature is saturated. As a result, the lower the temperature in the cyclone separator, the higher the aquadest output.

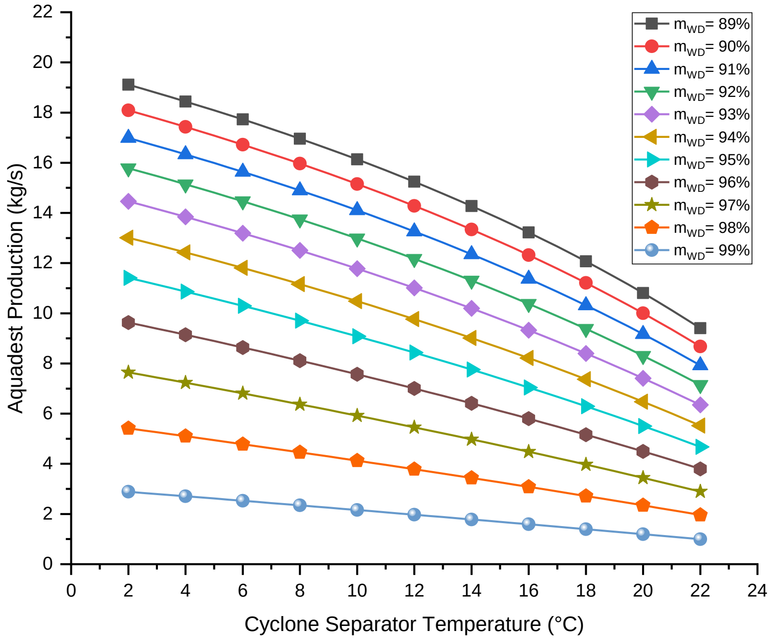

Fig. 8. Graph Aquadest Production vs. Temperature in cyclone separator at different percentages of mass water discharge.

Plot the percent change in mass water discharge (m_{Wd}) from 89 to 99 percent on a constant temperature scale of 2 to 22 °C as shown in Figure 9. Figure 9 depicts the relationship between mass water outflow and Specific Energy Consumption (SEC) proportion. The more mass water discharged to sea at a constant temperature in the cyclone separator, the less water throttled to a cyclone separator, resulting in lower aquadest production. Based on the previous research that has been done [24], as can be seen in Figure 10, the trend of SEC values also decreases with increasing percentage of mass water discharge. The SEC value obtained was lower by 56.4 kJ/kg aq under conditions of temperature at a cyclone separator of 22 °C and a percentage of mass water discharge of 99% when compared to previous studies.

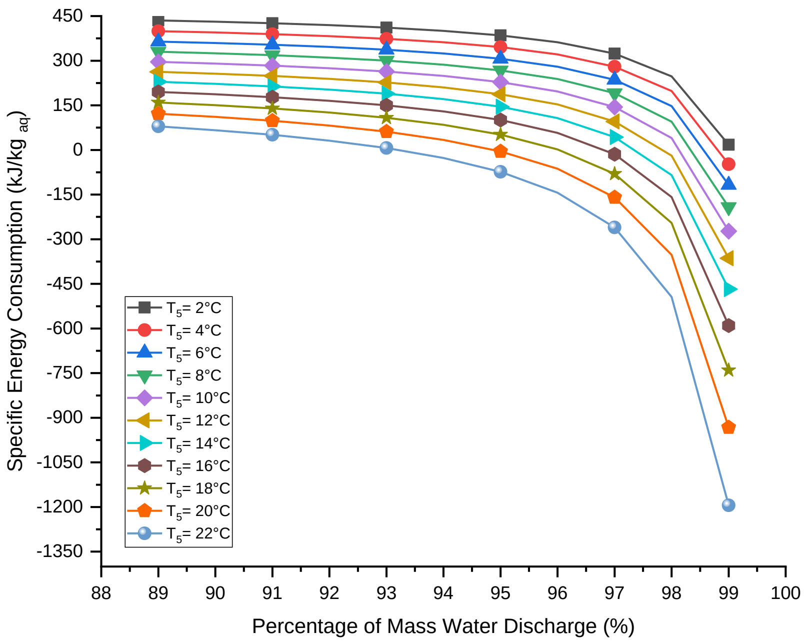

Fig. 9. Graph Specific Energy Consumption vs. Percentage of mass water discharge at different temperatures in a cyclone separator

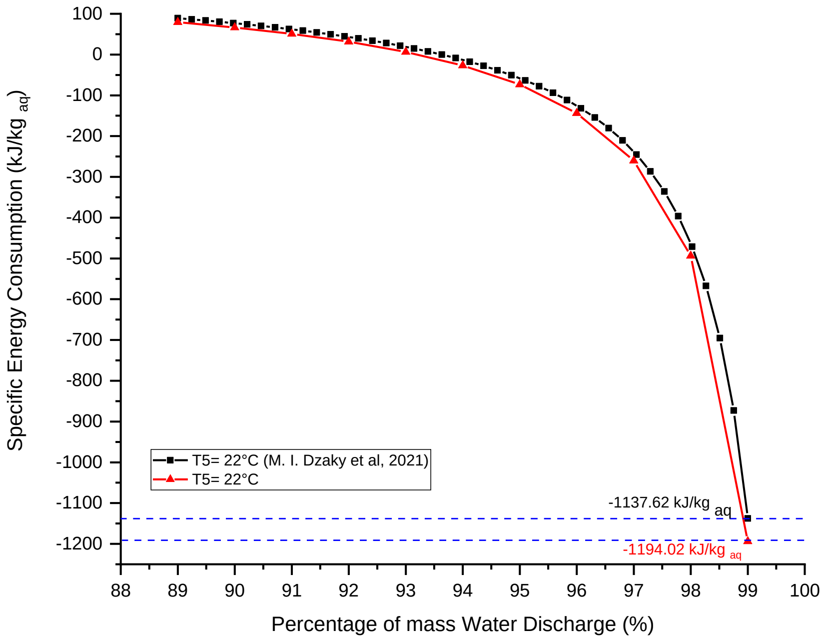

Fig. 10. Graph Specific Energy Consumption vs. percentage of mass water discharge previous [24] and currently research

4. Conclusions

Based on the simulation results of the steam power plant system combined with a desalination plant, it can conclude the optimum condition is as follow

i. The effect of lowering the temperature of the condenser to 41.5°C with the PPTD is 10 will increase the added power of the steam power plant. Furthermore, the temperature discharge to sea is safer for the environment at 31.5°C.

ii. The mass of water discharged to the sea is 99%, and 1% will process to the throttling valve. The lowered percentage of water throttling, the lowest energy consumption of the system.
iii. The temperature in the cyclone separator is 22°C for the lowest energy consumption of the vapor compressor.
iv. The best SEC is -1194.02kJ/kg aquadest, and the aquadest production is 0.996 kg/s aquadest.

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